COUNTERMOVEMENT JUMP STANDARDS IN RUGBY LEAGUE: WHAT IS A 'GOOD' PERFORMANCE?

Submission Type: Original Research

Funding Statement: No funding was received for this study.

Conflict of Interest Statement: There are no conflicts of interest concerning this study.

Authors: John J. McMahon[1], Jason P. Lake[2], Thomas Dos'Santos[1], Paul A. Jones[1], Michael L. Thomasson[1] and Paul Comfort[1]

Affiliations:

[1]McMahon, Dos'Santos, Jones, Thomasson and Comfort are with the Directorate of Psychology and Sport, University of Salford, Salford, Greater Manchester, M6 6PU, UK.

[2]Lake is with the Department of Sport and Exercise Sciences, University of Chichester, Chichester, West Sussex, PO19 6PE, UK.

Corresponding Author: Address author correspondence to John J. McMahon at j.j.mcmahon@salford.ac.uk or telephone +44(0)161 295 3892

Preferred Running Head: Jump Performance Standards in Rugby League

ABSTRACT

The countermovement jump (CMJ) is considered an important test in rugby league and the force platform is the recommended tool for assessing CMJ performance in this cohort. Due to inconsistent methods applied across previous studies, there is currently a lack of understanding of what constitutes a 'good' CMJ performance, with respect to the typical CMJ metrics that are reported for rugby league players. The purpose of this study was, therefore, to produce a scale of reference values for the jump height (JH), reactive strength index modified (RSI_{mod}) and mean (PP_{mean}) and peak (PP_{peak}) propulsion power (relative to body mass) for top-level senior rugby league players competing in the global 'forward' and 'back' positional groups. One hundred and four players (55 forwards and 49 backs) from the top two tiers of English rugby league performed three CMJs on a force platform at the beginning of pre-season training. The JH, RSI_{mod}, PP_{mean} and PP_{peak} were calculated using criterion methods and a scale of norm-referenced values (percentiles) was produced for each positional group. The backs outperformed the forwards for each CMJ metric reported, thus supporting the production of position-specific norm-referenced values. When each positional group was separated into quartile sub-groups, the respective JH, RSI_{mod}, PP_{mean} and PP_{peak} values were mostly largely and significantly different both within and between positions. The presented scale of reference values can, therefore, be used to determine the performance standards of rugby league forwards and backs with respect to the most commonly reported CMJ-derived variables for this cohort.

KEYWORDS

Vertical jump; force platform; normative data; talent identification; reactive strength index modified; power

INTRODUCTION

The countermovement jump (CMJ) has been suggested to be an important test in rugby league given that the CMJ height distinguishes between age groups (25) and shares positive associations with faster 5 m, 10 m and 30 m sprint performances (r=0.56-0.62, p<0.05) (3) and better tackling ability (r=0.38, p<0.05) (6) in this sport. It has been recommended that CMJ testing in rugby league should ideally be performed using a force platform (13, 26). This recommendation has since been supported by recent empirical studies that have revealed specific CMJ force-time variables that, alongside jump height (JH), distinguish between levels of play in rugby league. Such variables, include reactive strength index modified (RSI_{mod}) (4, 17) and mean (PP_{mean}) and peak (PP_{peak}) propulsion power (7), both of which can easily be derived from CMJ force-time records provided that criterion methods of data collection and analyses are adhered to (22). However, because of methodological inconsistences between studies that have included the assessment of CMJ force-time characteristics of rugby league players, it is impossible to confidently compare variables such as JH, RSI_{mod}, PP_{mean} and PP_{peak} between studies. Methodological inconsistencies and the omission of key methodological information (e.g. sample frequency, JH calculations, phase identification procedures), also makes it difficult for rugby league practitioners who routinely conduct CMJ force-time assessments to compare their players' data to those reported in the scientific literature.

In addition to methodological issues making it difficult to compare rugby league players' CMJ force-time data between studies , there is also a lack of understanding of what is a 'good' CMJ performance, with respect to JH, RSI_{mod}, PP_{mean} and PP_{peak} when the criterion methodology is applied. Moreover, given the large range of body mass values reported within rugby league, it is unclear as to whether a 'good' score differs for the heavier forwards versus the lighter backs (8). Because JH, RSI_{mod}, PP_{mean} and PP_{peak} are directly and largely influenced by propulsion velocity, being heavier will impede performance unless a suitably larger net propulsion force is produced (based on the impulse-momentum relationship). Currently, however, there is no guidance available for researchers and practitioners when it comes to evaluating rugby league players' CMJ performances, particularly with respect to the two global positional groups, to help facilitate their subsequent decision making on player-specific training foci. This presents a gap in the associated scientific literature which, if addressed, could facilitate a better connection between CMJ testing and training program design.

One recent study produced a preliminary scale of norm-referenced values (percentiles) for interpreting RSI_{mod} scores in NCAA Division I collegiate athletes (24). Although the evaluation of performance test data can be achieved via alternate means, norm-referenced values are simple to interpret and provide researchers and practitioners with a general idea of how individuals compare to the representative population (24). This approach could, therefore, be a suitable option for facilitating the evaluation of rugby league players' CMJ height, RSI_{mod}, PP_{mean} and PP_{peak}. Providing these norm-referenced values for forwards and backs separately could further aid player-specific training decisions in rugby league, owing to the reported differences in their body mass and match demands (8). The primary purpose of this study was, therefore, to produce a scale of reference values for the CMJ height, RSI_{mod}, PP_{mean} and PP_{peak} obtained by top-level senior rugby league players competing in the global 'forward' and 'back' positional groups. A secondary purpose of this study was to compare the CMJ height, RSI_{mod}, PP_{mean} and PP_{peak} scores attained by each positional group to inform the efficacy of creating separate norm-referenced values for forwards and backs.

METHODS

Experimental Approach to the Problem

A within-session repeated measures design was adopted for this study, whereby subjects (top-level rugby league players) performed three CMJs on a force platform, from which JH, RSI_{mod}, PP_{mean} and PP_{peak} were subsequently calculated.

Subjects

In England, the highest and second highest tier of competitive rugby league is the Super League (SL) and Rugby League Championship (RLC), respectively, which are both comprised of 12 teams. Between 2015 and 2018 (within the timeframe of testing), the professional SL teams regularly competed against the mostly semi-professional RLC teams and so teams from both leagues were included in this study. Thus, 104 rugby league players from the English SL (n=42) and RLC (n=62), comprised of 55 forwards and 49 backs, attended a single testing session during the first week of their respective preseason training periods (4, 7, 14). Each group's physical characteristics are compared in Table 1. Subjects had previous experience of performing CMJs in line with the protocols discussed in the procedures section. Written informed consent was provided prior to testing, which was pre-approved by the institutional review board and conformed to the World Medical Association's Declaration of Helsinki.

Procedures

Following a brief (approximately 10 min) warm-up consisting of dynamic stretching and sub-maximal jumping (five sets of single effort and two sets of five repeated CMJs), the subjects performed three recorded maximal effort CMJs, with the countermovement performed to a self-selected depth (9, 16). Jumps were separated by one-minute of rest. Subjects were instructed to perform the jumps as fast and as high as possible, whilst keeping their arms akimbo. Any jumps that were inadvertently performed with the inclusion of arm swing were omitted and additional jumps were performed after one minute of rest.

Ground reaction forces during the maximal effort CMJs were recorded at 1000 Hz using a Kistler type 9286AA force platform and Bioware 5.11 software (Kistler Instruments Inc., Amherst, NY, USA). Subjects were instructed to stand still for the initial one second of data collection (21, 22) to enable the subsequent determination of body weight (vertical force averaged over one second). Raw vertical force-time data were exported as text files and analyzed using a customized Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA).

Center of mass velocity was determined on sample-by-sample basis by dividing vertical force (minus body weight) by body mass and then integrating the product using the trapezoid rule (21). Instantaneous power throughout the jump was then calculated by multiplying force by velocity for successive samples. The CMJ start was identified using the criterion method (22) and take-off was identified when vertical force fell below five times the standard deviation of the flight phase force (11, 12). The propulsion phase of the CMJ was deemed to have started when velocity exceeded 0.01 $m \cdot s^{-1}$ and finished at take-off (17, 18). The PP_{mean} and PP_{peak} were calculated as the mean and maximum power values, respectively, attained during propulsion phase of the jump. Mean and peak propulsion power values were then ratio scaled by dividing the power value by body mass (14). The JH was derived from vertical velocity at take-off (21). The RSI_{mod} was calculated as JH divided by time to take-off (5). Time to take-off was calculated as the time interval between CMJ start and take-off.

Statistical Analyses

A two-way mixed-effects model (average measures) intraclass correlation coefficient (ICC), along with the upper and lower 95% confidence interval (CI), was used to determine the relative between-trial reliability of JH, RSI_{mod}, PP_{mean} and PP_{peak}. Based on the 95% CI of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.90, and greater than 0.90 indicated poor, moderate, good, and excellent relative reliability, respectively (10). Absolute between-trial reliability of each variable was calculated using the coefficient of variation percentage (CV%, calculated in this study as the standard deviation divided by the mean, expressed as a percentage), along with the upper and lower 95% CI. A CV of ≤10% and ≤5% has been used to indicate reliability in previous similar studies (2, 23). Therefore, <5% and 5-10% thresholds (based on the 95% CI of the CV% estimate) were considered to represent good and excellent reliability, respectively, in the present study (16).

A Shapiro-Wilks test was conducted to assess normality of data distribution. All data for the 'global' forwards and backs groups were normally distributed and so the primary variables were compared between these groups via the independent t-test. A Levene's test was used to assess the assumption of the equality of variances and that adjusted t statistic and degrees of freedom was adopted with variances that were not assumed to be equal. Percentiles were created for the forwards and backs groups with respect to JH, RSI_{mod}, PP_{mean} and PP_{peak}. A comparison of the mean JH, RSI_{mod}, PP_{mean} and PP_{peak} attained by each quartile (upper, upper-middle, lower-middle, lower) both within and between the forwards and backs positional groups was conducted via combination of series of one-way analysis of variances and Kruskal-Wallis tests. When a one-way analysis of variance was conducted, all subsequent pair-wise comparisons were Bonferroni corrected prior to being presented. When the Kruskal-Wallis test identified significant differences between groups, Mann-Whitney tests were conducted to obtain pair-wise comparison and manually corrected. Effect sizes (Hedge's *g*) were calculated to highlight the magnitude of mean differences between groups and they were interpreted as trivial (≤0.19), small (0.20-0.49), moderate (0.50-0.79), or large (≥0.80). All statistical analyses, apart from the CV%, effect size and percentile calculations which were calculated in Microsoft Excel, were performed using SPSS software (version 25; SPSS Inc., Chicago, IL, USA) with the alpha level set at $p<0.05$.

RESULTS

There were non-significant and trivial-small differences between SL and RLC players in JH ($p=0.474$, $g=0.13$), RSI_{mod} ($p=0.222$, $g=0.27$), PP_{mean} ($p=0.474$, $g=0.14$) and PP_{peak} ($p=0.292$, $g=0.10$). The combining of SL and RLC players' data in the subsequent statistical analyses was, therefore, deemed to be acceptable.

The physical characteristics of the forwards and backs can be seen in Table 1. Age was identical between groups, but the forwards were taller and heavier than the backs (Table 1).

Table 1: A comparison of physical characteristics of the forwards (*n*=55) and backs (*n*=49).

Variables	Forwards		Backs		Comparison	
	Mean	SD	Mean	SD	*p*	*g*
Age (years)	24.6	4.0	24.6	4.0	0.90	0.00
Height (m)	1.84	0.06	1.81	0.06	0.01	0.50
Body Mass (kg)	101.5	9.3	89.8	7.9	<0.01	1.34

The JH, PP_{mean} and PP_{peak} demonstrated excellent reliability, whereas RSI_{mod} showed good-excellent reliability, for both the backs and the forwards (Figures 1-2). Backs demonstrated a small and significantly greater JH (0.36±0.05 vs. 0.34±0.04 m; $p=0.025$, $g=0.44$) and RSI_{mod} (0.48±0.08 vs. 0.45±0.08; $p=0.013$, $g=0.37$) than forwards (Figures 3-4). Backs also demonstrated a moderate and significantly greater PP_{mean} (31.5±3.2 vs. 29.1±3.6 $W \cdot kg^{-1}$; $p=0.004$, $g=0.70$) and PP_{peak} (54.4±4.7 vs. 51.3±4.8 $W \cdot kg^{-1}$; $p=0.001$, $g=0.65$) than forwards (Figures 5-6). The separating of forwards' and backs' data in the subsequent statistical analyses was, therefore, deemed to be acceptable. The scale of reference values for JH, RSI_{mod}, PP_{mean} and PP_{peak} are shown in Tables 2 and 3.

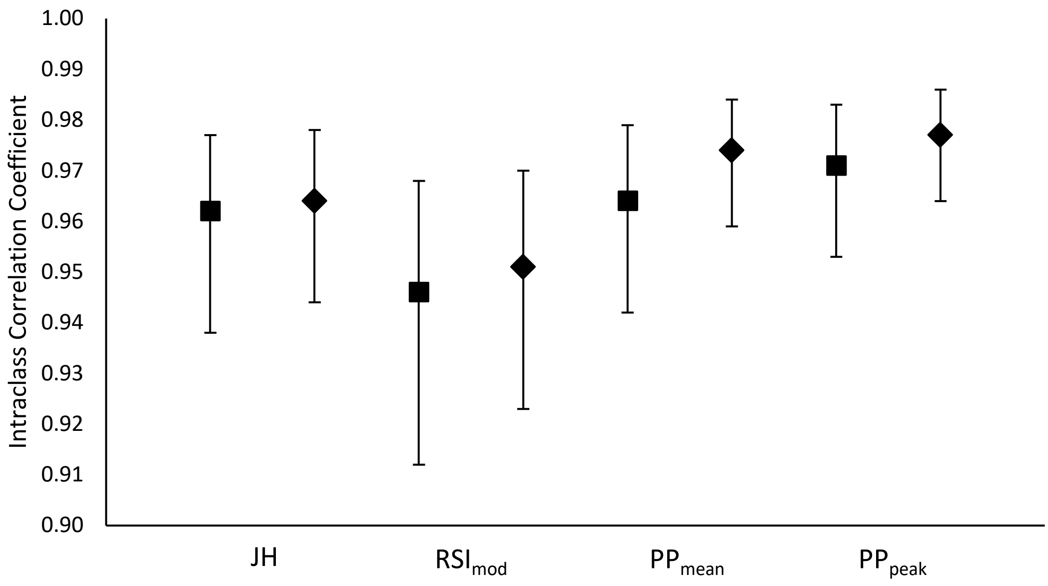

Figure 1: Intraclass correlation coefficients (±95% confidence intervals) for backs' (squares) and forwards' (diamonds) data. JH = jump height, RSI_{mod} = reactive strength index modified, PP = propulsion power.

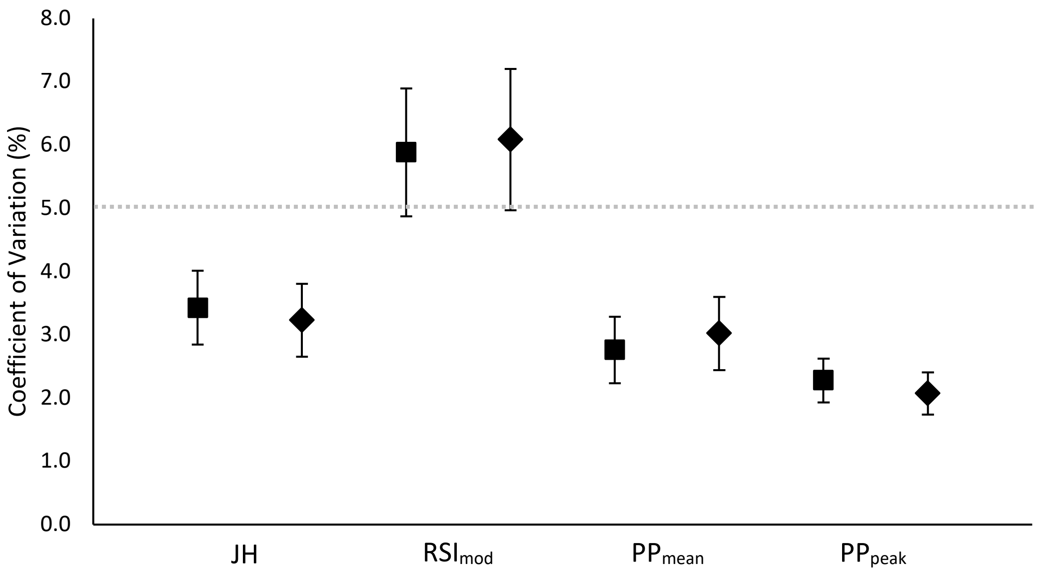

Figure 2: Coefficient of variation percentages (±95% confidence intervals) for backs' (squares) and forwards' (diamonds) data. The grey line denotes the threshold used to interpret good (5-10%) and excellent (0-5%) scores. JH = jump height, RSI_{mod} = reactive strength index modified, PP = propulsion power.

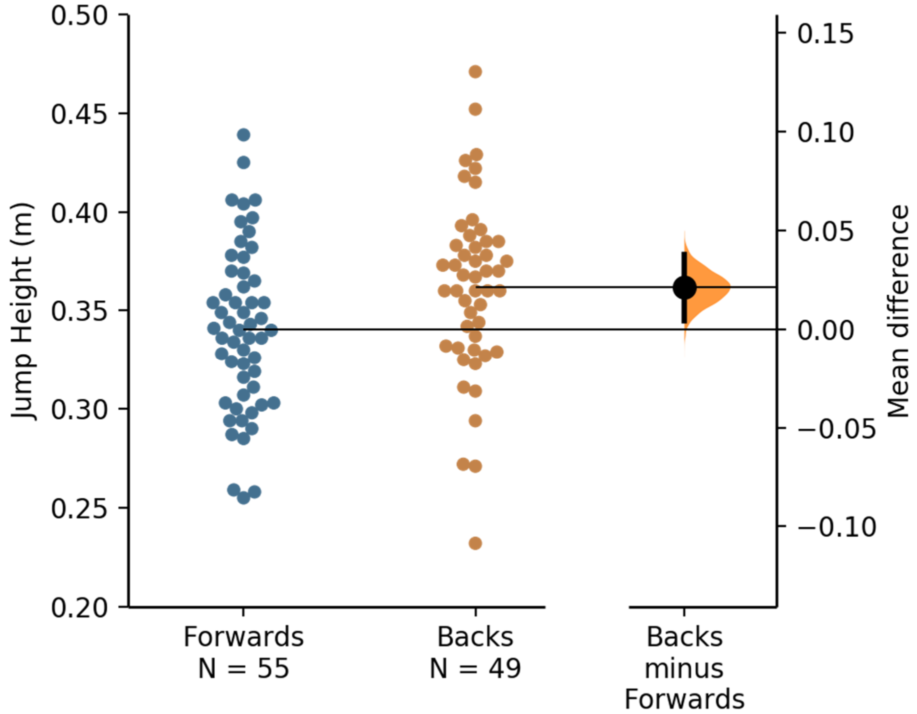

Figure 3: Data distribution and mean differences in jump height between forwards and backs.

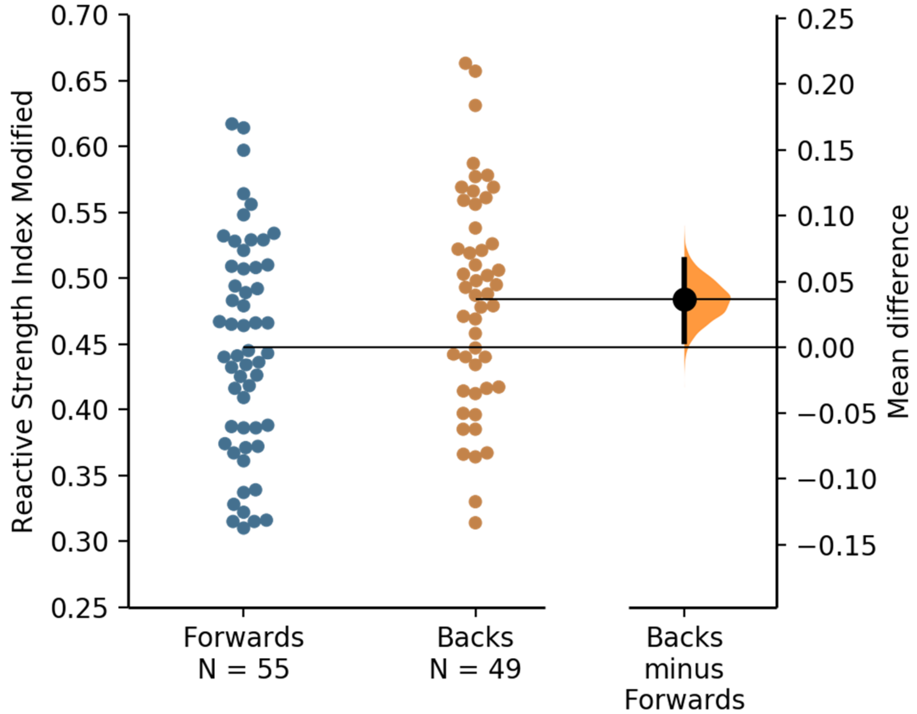

Figure 4: Data distribution and mean differences in reactive strength index modified between forwards and backs.

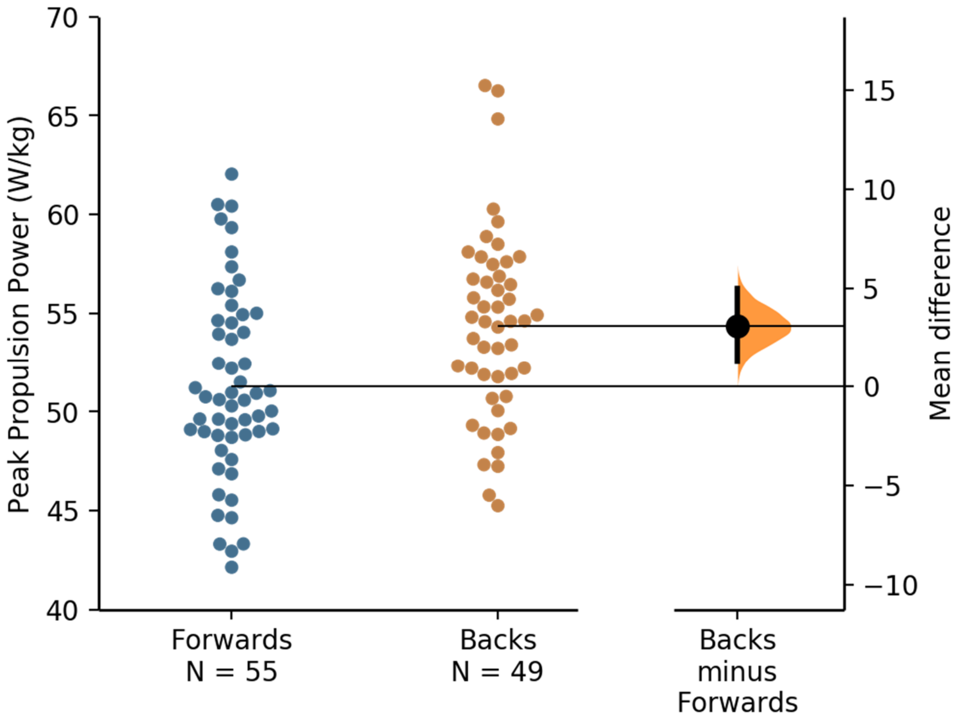

Figure 5: Data distribution and mean differences in peak propulsion power between forwards and backs.

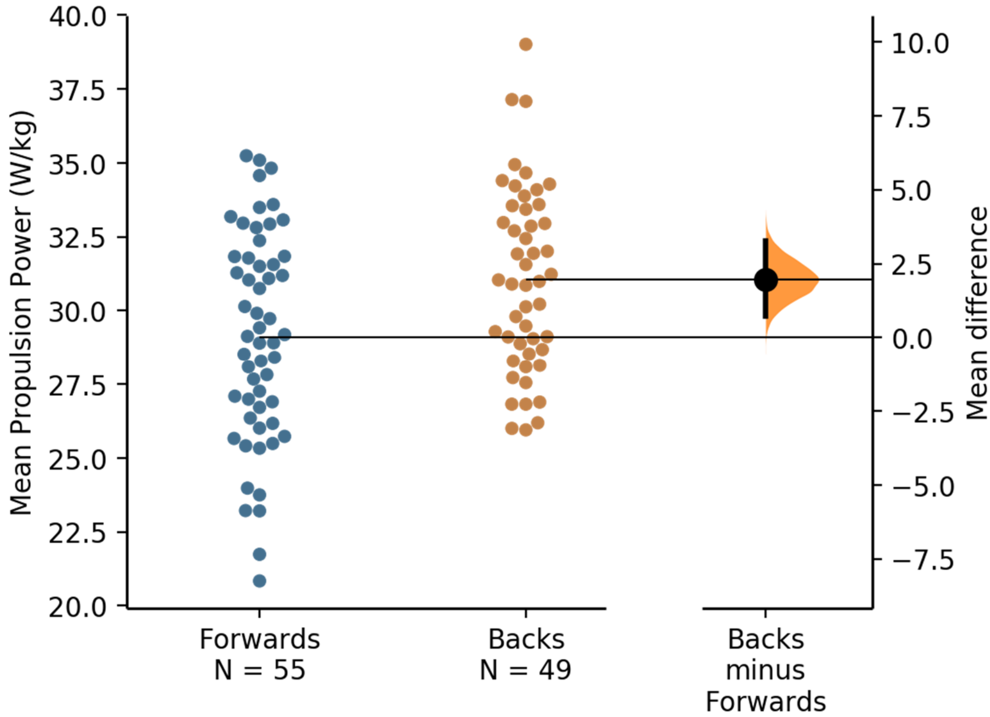

Figure 6: Data distribution and mean differences in mean propulsion power between forwards and backs.

Table 2: Scale of reference values for jump height and reactive strength index modified for forwards (*n*=55) and backs (*n*=49).

	Jump Height (m)		Reactive Strength Index Modified	
Percentile	**Forwards**	**Backs**	**Forwards**	**Backs**
97	0.429	0.462	0.615	0.660
95	0.410	0.441	0.601	0.644
90	0.400	0.422	0.551	0.578
85	0.388	0.406	0.531	0.569
80	0.378	0.391	0.527	0.561
75	***0.369***	***0.385***	***0.509***	***0.547***
70	0.359	0.382	0.496	0.522
65	0.354	0.376	0.486	0.514
60	0.349	0.373	0.467	0.503
55	0.344	0.370	0.465	0.496
50	***0.340***	***0.367***	***0.443***	***0.488***
45	0.336	0.360	0.437	0.479
40	0.331	0.360	0.428	0.469
35	0.325	0.351	0.417	0.445
30	0.318	0.342	0.387	0.440
25	***0.307***	***0.332***	***0.386***	***0.417***
20	0.302	0.329	0.371	0.412
15	0.296	0.324	0.348	0.391
10	0.289	0.309	0.325	0.367
5	0.259	0.271	0.315	0.347
3	0.257	0.251	0.313	0.322

The mean JH, RSI_{mod}, PP_{mean} and PP_{peak} was significantly different between all quartile sub-groups of the forwards (p<0.001, g=2.44-6.69). Similarly, the mean JH, RSI_{mod}, PP_{mean} and PP_{peak} was significantly different between all quartile sub-groups of the backs (p<0.001, g=1.84-5.91), except for the difference in mean JH between the upper middle and lower middle quartile groups, although a large effect size was still noted (p=0.067, g=1.99).

Table 3: Scale of reference values for peak and mean propulsion power for forwards (*n*=55) and backs (*n*=49).

	Peak Power ($W \cdot kg^{-1}$)		Mean Power ($W \cdot kg^{-1}$)	
Percentile	**Forwards**	**Backs**	**Forwards**	**Backs**
97	61.0	66.4	35.1	38.1
95	60.4	65.5	34.9	37.1
90	58.6	59.6	33.5	34.7
85	56.5	58.3	33.0	34.3
80	55.3	57.8	32.7	33.9
75	***54.6***	***57.2***	***31.8***	***33.5***
70	54.0	56.6	31.5	32.9
65	52.4	56.0	31.1	32.6
60	51.4	55.3	30.5	31.9
55	51.0	54.9	29.7	31.4
50	***50.6***	***54.6***	***29.1***	***31.0***
45	50.1	54.0	28.6	30.5
40	49.6	53.3	28.2	29.8
35	49.3	52.3	27.5	29.2
30	49.0	51.9	27.0	29.0
25	***48.8***	***51.3***	***26.4***	***28.6***
20	47.7	50.1	25.8	28.1
15	46.2	49.0	25.4	27.6
10	44.7	47.9	23.9	26.8
5	43.2	46.5	22.9	26.1
3	42.7	45.5	21.5	26.0

When comparing the forwards and backs, there were moderate-large and significant differences between all quartile sub-groups for most variables. The JH difference between the upper and lower quartile sub-groups, the PP_{peak} difference between the upper quartile sub-groups, and RSI_{mod} difference between the upper-middle quartile sub-groups were the only non-significant comparisons, although small-large effect sizes were still identified (Table 4).

Table 4: A comparison of performance between forwards and backs across quartile sub-groups.

Variable	Quartile	Forwards			Backs			Comparison	
		n	**Mean**	**SD**	***n***	**Mean**	**SD**	***p***	***g***
Jump Height (m)	Upper	14	0.39	0.02	13	0.41	0.03	0.27	0.78
	Upper-Middle	15	0.35	0.01	12	0.37	0.01	0.03	1.90
	Lower-Middle	13	0.33	0.01	12	0.35	0.01	0.02	1.93
	Lower	13	0.29	0.02	12	0.30	0.03	0.04	0.38
Reactive Strength Index Modified	Upper	14	0.55	0.04	12	0.59	0.04	0.02	0.97
	Upper-Middle	14	0.47	0.02	13	0.51	0.01	0.08	2.42
	Lower-Middle	14	0.42	0.02	12	0.46	0.02	<0.01	1.94
	Lower	13	0.34	0.02	12	0.38	0.03	0.02	1.53
Mean Propulsion Power ($W \cdot kg^{-1}$)	Upper	14	33.4	1.1	12	35.1	1.7	0.01	1.17
	Upper-Middle	14	30.4	1.0	13	32.2	0.8	0.02	1.92
	Lower-Middle	14	27.7	0.8	12	29.6	0.8	<0.01	2.30
	Lower	13	24.4	1.7	12	27.2	0.9	<0.01	1.97
Peak Propulsion Power ($W \cdot kg^{-1}$)	Upper	14	57.6	2.4	12	60.3	3.5	0.07	0.88
	Upper-Middle	14	52.1	1.4	13	55.7	0.8	<0.01	3.03
	Lower-Middle	14	49.5	0.5	12	52.9	1.0	<0.01	4.27
	Lower	13	45.4	2.1	12	48.4	1.8	0.01	1.48

DISCUSSION

The primary purpose of this study was to produce a scale of reference values for CMJ-derived JH, RSI_{mod}, PP_{mean} and PP_{peak} based on data obtained by top-level senior rugby league players who, at the time of testing, competed in the global 'forward' and 'back' positional groups for either a SL or RLC club in the United Kingdom. The data presented were reliable (Figures 1-2) and significant positional differences were noted, thus both enabling and rationalizing the production of position-specific reference values for each variable (Tables 2-3). Furthermore, there were mostly large and significant differences in mean JH, RSI_{mod}, PP_{mean} and PP_{peak} both within- and between-position quartile sub-groups (Table 4). The presented scale of reference values, therefore, demonstrate the potential to discriminate between rugby league positional groups, albeit at a global level, and between levels of attainment within these positional groups with respect to the most commonly reported CMJ-derived variables in rugby league studies. The reason for positional differences in CMJ performance is likely attributed to the large and significant differences in body mass noted (Table 1), meaning that the heavier forwards were required to produce a suitably larger net propulsion force to match the take-off velocity of the lighter backs (this is discussed further below). When reviewing the CMJ performance data distribution (Figures 3-6), there is some overlap in performances of the forwards and backs but when considering the overall mean and quartile mean performances of each group, the backs almost consistently outperform the forwards.

The mean CMJ heights reported here for the backs and forwards were lower than those reported (42.5±5.2 cm) in a recent study by Dobbin et al. (4) and there are several possible explanations for this. Firstly, Dobbin et al. (4) assessed CMJ height via a jump mat and although they corrected for the known error associated with the jump mat, the presented JH values were still derived from the flight time method which tends to overestimate true JH (19). Secondly, Dobbin et al. (4) reported the highest JH performed by each player rather than the mean, with the latter approach having been recently recommended to avoid the generation of random jump height scores (9). Lastly, the players tested by Dobbin et al. (4) were all part of SL teams only and so the inclusion of RLC teams in the present study led to a slight reduction in mean JH scores. In agreement, the results of a recent study comprised of a smaller number of SL and RLC players showed that the former attained superior JH values (14). However, the difference in JH obtained the SL and RLC players in the present study was not significantly different (p=0.474, g=0.13) which is why their data were pooled. The mean JH values reported in our study were similar to those reported by Ireton et al. (7) who, like us, derived JH from a force platform in a smaller sample of 18 senior SL players (0.34±0.11 m). The CMJ PP_{mean} and PP_{peak} values were reported in absolute terms only by Ireton et al. (7) but, again, were found to be similar (from dividing the mean PP_{mean} and PP_{peak} values by mean body mass) to those attained by the forwards in the present study. The presence of both between-study differences and similarities in rugby league players' CMJ height, PP_{mean} and PP_{peak} values highlights the importance of standardizing the CMJ data collection procedures within this sport. To the authors' knowledge, the only previous studies to report RSI_{mod} in rugby league cohorts are from our own laboratory whereby the same methods as those adopted in the present study were included, thus, the mean RSI_{mod} values reported here are similar to those previously reported (14, 15, 17, 20).

Before the reader decides to refer to the presented scale of reference values when evaluating their own rugby league players' CMJ performances, it is important to contextualize the information presented by critically apprising the strengths and limitations of the work. The major strengths of the present study are that it included a relatively large sample of rugby league players from multiple SL and RLC clubs who were tested at the same time of the season with the same force platform and whose data were collected and analysed in line with well-established criterion recommendations. The scale of reference values reported here can, therefore, be considered especially useful for comparing top-level senior rugby league players' data at the start of preseason or after a short period of no training. These data are perhaps less useful for exploring in-season CMJ performances without accounting also for influential factors like fluctuations in training and competition volume loads. Nevertheless, practitioners can compare in-season CMJ performances to those attained at the start of the pre-season to check whether their players' data improves, maintains or declines and then refer to the presented norm-referenced values to check whether they have changed their percentile rank. Finally, in a previous study of rugby league players the authors reported both PP_{mean} and PP_{peak} to be highly related (r=0.90 and r=0.74, respectively) to RSI_{mod} (15). Therefore, there is likely little need to evaluate each of these variables when monitoring rugby league players' CMJ performances. Each of them (i.e. PP_{mean}, PP_{peak} and RSI_{mod}) are presented in this study because they are the most common CMJ variables reported in rugby league studies (4, 7, 17), but it would be prudent for practitioners to be selective with the CMJ variables that they decide to monitor, by developing a clear rationale for their inclusion, to improve efficiency and clarity of performance data reporting.

The backs were significantly lighter than the forwards in the present study (Table 1). Any heavier athlete must push harder (apply more force) in the propulsion phase of the CMJ to attain the same take-off velocity as a lighter counterpart. Any heavier athlete will also likely experience more deceleration just prior to take-off (i.e. a greater decline in peak propulsion velocity due to 'picking up' the weight of the shanks and feet). Therefore, a heavier athlete must push harder via forceful extension of ankles, knees and hips to attain the same JH (assuming an identical propulsion displacement), irrespective of the jump test performed. Alternatively, if more force cannot be produced, heavier athletes require either a longer time or displacement, or likely both, during propulsion to attain the same take-off velocity. However, most sporting actions are time constrained, therefore relying on a jump strategy such as this would likely be counterproductive. It must be noted, however, that in a collision sport such as rugby league, momentum (calculated as body mass times velocity) is likely to be a more important factor than velocity alone (1). This, indeed, is why sprinting momentum is now more commonly reported than sprinting velocity or split times in rugby cohorts. The presently included CMJ variables, despite being the most commonly reported in rugby league studies, are all biased in favor of lighter athletes. Future research avenues should, therefore, include the identification of alternative force platform derived CMJ variables that may be more applicable to collision sport athletes who are not only required to be able to effectively accelerate their own body mass but also the body masses of their opponents.

The authors would like to conclude by clearly stressing the importance of combining the results of athlete's CMJ testing with other test data and relevant information about the athlete. For example, if an athlete is in the upper quartile for JH but lower-middle quartile for RSI_{mod} then it is likely that they have a longer than preferable time to take-off. The question for the practitioner to ask, therefore, is why is the time to take-off too long and is this something that needs to be addressed? There may be multiple answers to the first question such as did the player fully-understand the test instruction, were they motivated to put in a maximal-effort, are they among the taller and/or heavier players in the squad, did their prior training cycle address rapid force production, are they recovering from a lower limb injury or previous match? Comparing any rugby league player's data to the scale of reference values shown in Tables 2-3 only provides insight into 'how' the player performed in the CMJ with respect to the data reported in this study. Identifying 'why' they performed above, as expected, or below standard in the CMJ cannot be informed by any information presented in this study but, instead, will require further investigation of factors such as the player's training and competition volume loads prior to testing as well as performance in other physical tests (e.g. strength and speed tests).

PRACTICAL APPLICATIONS

The present study has produced a scale of reference values for CMJ-derived JH, RSI_{mod}, PP_{mean} and PP_{peak} based on data obtained by 104 top-level senior rugby league players who competed in the global 'forward' (n=55) and 'back' (n=49) positional groups. These data were collected via force platform and subsequently analysed in line with well-established criterion methods, as is recommended when testing the CMJ performances of rugby league players (13). The scale of reference values reported in this study will, therefore, be useful to researchers and practitioners who wish to evaluate other top-level senior rugby league players' CMJ performances, provided that the data are collected and analyzed in the same manner. It is recommended, however, that rugby league researchers and practitioners do not monitor each of these variables due to them being highly correlated (15). We also strongly recommend that, where possible, rugby league researchers and practitioners should consider other relevant test data (e.g. strength, speed) and information (e.g. height, body mass, training volume) about their athletes before making any definitive training decisions.

REFERENCES

1. Baker D and Newton R. Comparison of Lower Body Strength, Power, Acceleration, Speed, Agility, and Sprint Momentum to Describe and Compare Playing Rank among Professional Rugby League Players. *J Strength Cond Res* 22: 153, 2008.
2. Cormack SJ, Newton RU, McGuigan MR, and Doyle TLA. Reliability of Measures Obtained during Single and Repeated Countermovement Jumps. *Int J Sport Physiol Perform* 3: 131-144, 2008.
3. Cronin JB and Hansen KT. Strength and power predictors of sports speed. *J Strength Cond Res* 19: 349-357, 2005.
4. Dobbin N, Highton J, Moss SL, and Twist C. The Discriminant Validity of a Standardized Testing Battery and Its Ability to Differentiate Anthropometric and Physical Characteristics Between Youth, Academy, and Senior Professional Rugby League Players. *Int J Sport Physiol Perform* 14: 1110-1116, Publish Ahead of Print.
5. Ebben WP and Petushek EJ. Using the Reactive Strength Index Modified to Evaluate Plyometric Performance. *J Strength Cond Res* 24: 1983-1987, 2010.
6. Gabbett TJ, Jenkins DG, and Abernethy B. Correlates of Tackling Ability in High-Performance Rugby League Players. *J Strength Cond Res* 25: 72-79, 2011.
7. Ireton MRE, Till K, Weaving D, and Jones B. Differences in the Movement Skills and Physical Qualities of Elite Senior & Academy Rugby League Players. *J Strength Cond Res*, Publish Ahead of Print.
8. Jones B, Till K, Barlow M, Lees M, O'Hara JP, and Hind K. Anthropometric and Three-Compartment Body Composition Differences between Super League and Championship Rugby League Players: Considerations for the 2015 Season and Beyond. *PloS one* 10: e0133188-e0133188, 2015.
9. Kennedy RA and Drake D. Improving the Signal-To-Noise Ratio When Monitoring Countermovement Jump Performance. *J Strength Cond Res*, Publish Ahead of Print.
10. Koo TK and Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med* 15: 155-163, 2016.
11. Lake J, Mundy P, Comfort P, McMahon JJ, Suchomel TJ, and Carden P. Concurrent Validity of a Portable Force Plate Using Vertical Jump Force-Time Characteristics. *J Appl Biomech*, 34: 410-413, 2018.
12. Lake JP, Mundy PD, Comfort P, McMahon JJ, Suchomel TJ, and Carden P. The effect of barbell load on vertical jump landing force-time characteristics. *J Strength Cond Res*, Publish Ahead of Print.
13. McMahon JJ, Jones PA, and Comfort P. Comment on: "Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players". *Sport Med* 47: 2667-2668, 2017.
14. McMahon JJ, Jones PA, and Comfort P. Comparison of countermovement jump-derived reactive strength index modified and underpinning force-time variables between super league and championship rugby league players. *J Strength Cond Res*, Publish Ahead of Print.
15. McMahon JJ, Jones PA, Suchomel TJ, Lake J, and Comfort P. Influence of Reactive Strength Index Modified on Force- and Power-Time Curves. *Int J Sport Physiol Perform* 13: 220-227, 2018.
16. McMahon JJ, Lake JP, and Comfort P. Reliability of and Relationship between Flight Time to Contraction Time Ratio and Reactive Strength Index Modified. *Sports* 6, 2018.
17. McMahon JJ, Murphy S, Rej SJ, and Comfort P. Countermovement-Jump-Phase Characteristics of Senior and Academy Rugby League Players. *Int J Sport Physiol Perform* 12: 803-811, 2017.
18. McMahon JJ, Rej SJ, and Comfort P. Sex Differences in Countermovement Jump Phase Characteristics. *Sports* 5: 8, 2017.
19. McMahon JJ, Suchomel TJ, Lake JP, and Comfort P. Understanding the key phases of the countermovement jump force-time curve. *Strength Cond J* 40: 96-106, 2018.
20. McMahon JJ, Suchomel TJ, Lake JP, and Comfort P. Relationship between reactive strength index variants in rugby league players. *J Strength Cond Res* Publish Ahead of Print.

21. Moir GL. Three Different Methods of Calculating Vertical Jump Height from Force Platform Data in Men and Women. *Meas Phys Educ Exerc Sci* 12: 207-218, 2008.
22. Owen NJ, Watkins J, Kilduff LP, Bevan HR, and Bennett MA. Development of a Criterion Method to Determine Peak Mechanical Power Output in a Countermovement Jump. *J Strength Cond Res* 28: 1552-1558, 2014.
23. Roe G, Darrall-Jones J, Till K, Phibbs P, Read D, Weakley J, and Jones B. Between-Days Reliability and Sensitivity of Common Fatigue Measures in Rugby Players. *Int J Sport Physiol Perform* 11: 581-586, 2016.
24. Sole C, Suchomel T, and Stone M. Preliminary Scale of Reference Values for Evaluating Reactive Strength Index-Modified in Male and Female NCAA Division I Athletes. *Sports* 6: 133, 2018.
25. Till K, Scantlebury S, and Jones B. Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players. *Sport Med*: 1-16, 2017.
26. Till K, Scantlebury S, and Jones B. Author's Reply to McMahon et al. Comment on: "Anthropometric and Physical Qualities of Elite Male Youth Rugby League Players". *Sport Med* 47: 2669-2670, 2017.